

# FIRST YEAR DSP EDUCATION IN THE CONTEXT OF ECE CURRICULUM REFORM

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## ABSTRACT

Over time DSP education has tracked the evolution and growth of its theoretical foundations, hardware and implementation resources, and engineering education context. First year DSP courses have often had dual objectives of both motivating students to consider EE through an interesting first course and laboratory experience and also satisfying some part of the major curriculum requirements. Recent trends in engineering education and curriculum reform may offer opportunities to include DSP content in the early curriculum in a more distributed manner rather than as a single course. Reformed EE programs may focus on multidisciplinary and integrated freshman experiences in terms of design projects or specific context themes. This paper explores how DSP course content might be integrated into first year experiences in this context and explores implications with respect to concept continuity and assessment.

**Index Terms**— DSP education, first year, multidisciplinary course, complex systems, assessment

## 1. INTRODUCTION

Since the first Signal Processing Education Workshop in 2000, a number of engineering programs have introduced creative engaging first year courses either with a focus on digital signal processing (DSP) or with a broader focus that includes significant components with a DSP orientation. The widely adopted text, *Signal Processing First* [1] is an example of content selection and style for an introductory presentation of signal processing that does not have a long prerequisite list and can be used for both electrical engineering majors and nonmajors. Courses based on the DSP First concept [e.g. 2-5] and first and second year

courses [e.g. 6-9] were developed to meet some institutionally specific needs and some needs more general to the discipline. Programs have also been developed to bring DSP topics, especially audio and video, to high school students [10,11].

More recently a wide variety of first year engineering courses, often multidisciplinary, have been proposed and implemented to address a number of issues from a variety of perspectives, some of which may have conflicting objectives. To better understand future directions of first year courses and the role that DSP will play, it is important to understand the changing contexts of technological development, the dynamics and migration of engineering departmental structures and curricula, new ideas about general restructuring of engineering education, the expectations for the engineer of the future [12, 13], and the social perceptions of engineering [14].

The first attempts to move DSP from a senior level elective taken by a small number of engineering students to a lower division course for a much broader group of students addressed questions of whether or not it could be done and then how it could be done using newly available hardware and development tools. Looking forward, the DSP community needs to address questions of why DSP should be in first year courses, what parts of DSP are most suitable for early introduction, what pedagogical purposes are served by early introduction of DSP, how first year courses should be evaluated, and how DSP will fit into future trends in engineering education.

## 2. MOTIVATIONS FOR FIRST YEAR DSP COURSES

The content and style of digital signal processing in the engineering curriculum has been tied closely to the current context of new theoretical methods and the current level of development of enabling technologies for DSP

Report Documentation Page			Form Approved OMB No. 0704-0188		
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1. REPORT DATE <b>JAN 2009</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2009 to 00-00-2009</b>	
4. TITLE AND SUBTITLE <b>First Year DSP Education in the Context of ECE Curriculum Reform</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>National Science Foundation,ENG/EEC,4201 Wilson Boulevard,Arlington,VA,22230</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002264. Presented at the IEEE Digital Signal Processing Workshop (13th) and Signal Processing Education Workshop (5th) Held in Marco Island, Florida on 4-7 January 2009. Sponsored by ONR.</b>					
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15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>5</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

implementation. Early DSP courses were upper division or graduate electives with a strong mathematical emphasis and homework based on derivations and proofs. For a laboratory a student might write a Fortran program to implement a radix-2 FFT.

Advances in semiconductor technology, processor architectures, development tools and software for computation and visualization fundamentally changed commercial applications of DSP and resources available to educators. Instructors could reasonably include laboratory experiments to complement theoretical lecture presentations, and employers looked for graduates with some implementation experience, so most DSP courses adopted real-time laboratory components, often using audio signals.

In addition to better preparing students for the workforce, real-time signal processing laboratories with some audio examples could also improve students' concept development and theoretical understanding. For example, when listening to the audio output from a speaker, it is easy to distinguish a square wave from a pure sinusoid because of the harsh sound of the square wave harmonics. As the fundamental frequency of the square wave is increased while the signal is low pass filtered by speakers or the human ear, it is easy to hear the harmonics of a square wave fade to leave a pure tone. This experience could help many students more fully understand the concepts of Fourier series representation and frequency selective filtering before the mathematical derivations are clearly understood.

Initially the main drivers for moving a first DSP course to the lower division included both pedagogy and advances in technology. Traditionally DSP and other systems electives, such as communications and control, were taken by juniors and seniors who had completed prerequisite courses in circuits and linear systems. As hardware for real-time processing became available with appropriate development tools, the increased ease of implementing real-time DSP laboratory experiments made complex projects feasible and also allowed more entry level exploratory activities. In addition, progress in computational and visualization tools with MATLAB [15] and Java applets [16, 17] provided additional tools for understanding both fundamental and advanced concepts. With these new tools it became possible to meaningfully teach some parts of the first DSP course to students who had not had the linear systems prerequisite courses.

Since it was possible to teach DSP in the lower division, placement of a first course there could be justified in several ways. It could be argued that DSP covered a basic core subject area and for that reason it should be taken by all electrical engineering students. It could also be argued that understanding the acquisition, use, limitations, and processing of digitally acquired signals had become fundamental to engineering in other disciplines such as mechanical, civil, or bioengineering, and an entry level DSP

course was needed for those majors as well. In either case it was possible to identify a set of topics with broad application that was appropriate for an introductory level class. This created both problems and opportunities for articulation with the upper division options. Would an early DSP course be a prerequisite to a later elective course which might have room for more advanced content based on the assumption of the prerequisite? Would the advanced elective just assume basic exposure to DSP in the same way it assumes lower division exposure to calculus and differential equations? Would different universities present different subsets in the early courses?

Bringing DSP into the lower division, possibly as a core course, has implications about the changing relevance of the topic to the overall EE curriculum, and assessment of success should include that broader context. The early introduction of DSP puts digital discrete time concepts before continuous analog concepts and, like digital logic courses, often puts design before analysis. The impact of this reordering has not been easy to define. Typical assessments of individual classes consider the effects measured over the time that the course is given. It is far more difficult to determine the longer term effect of the early introduction of DSP concepts on students' performance in the circuits and systems courses they take later. Perhaps their progress is accelerated and later electives can be more advanced. Perhaps their understanding is deeper. Perhaps their comfort level is higher due to earlier exposure.

The rapid evolution of implementation options in recent years and a corresponding increase in implementation focus has further complicated the question of where DSP should be positioned [18, 19] and what topics should be included in a first DSP course. For example, increased throughput of a digital signal processing system used to depend on more efficient sequential algorithms and increased processor clock speed. Now increased throughput can be achieved with multiprocessor systems or massively parallel customized architectures using FPGAs. Development tools may use high level programming languages, or block diagram design, or hardware description languages. With this wide variety of options there are many alternatives for a first year topic set.

An implementation orientation also raises questions about the basic design units of DSP as well as the order in which concepts are introduced [20]. From the application perspective there can be debate about what topics are basic entry level DSP topics and what topics outside of the traditional DSP scope must also be included. For example, a course may combine DSP and other topics such as discrete mathematics or architecture. Some DSP may be required for instrumentation courses in other engineering majors using tools such as LabVIEW [21] for an introduction to actual and virtual instrumentation.

A more recent motivation for moving DSP to the lower division has been to increase excitement about electrical engineering and to increase enrollment and retention. Declining interest in EE for the current generation of students has led to efforts to put more engaging hands-on projects in the first year to balance the traditional core mathematics and science topics. Then students do not have to wait until the upper division to do projects they find interesting [e.g. 21, 22]. Assessments of first year courses from this perspective typically try to measure increased student enthusiasm for the major or increased student confidence or sense of purpose at the end of the course. However, with the crowded curriculum for most engineering majors, a course that excites students about the major must also play a role in teaching concepts, techniques, and technical understanding required for that major to achieve the desired learning outcomes. These must also be assessed.

Although students may express satisfaction with a first DSP course, other types of engaging first year courses have also been successful. Multidisciplinary robotics courses and community based projects, for example, may include some DSP in a broader context

### **3. DEPARTMENTAL LEVEL REFORM FOR EE**

On a national scale electrical engineering curricula are currently adapting to rapidly changing technology and changing demand for skills while engineering programs are engaged in a variety of experiments to improve recruitment and retention. This has led to proposed major restructurings of the traditional hierarchical delayed gratification curriculum and to attempts to align the curriculum more closely with current and perceived requirements for engineering graduates who can compete in the future globalized workplace [12, 13, 14, 23].

Although individual institutions have unique contexts and have developed a variety of narrow and broad scale curriculum changes within their context, there are common components in many of these new courses and curricula. In an attempt to increase relevance and student interest, a number of first year programs focus on a multidisciplinary engineering design projects in the context of a community or social need. Project based learning has been widely adopted and programs with a community service focus, such as EPICS [ 24, 25], have been attractive to students. Other first year programs may focus on a more narrowly defined technical design challenge, but still have a multidisciplinary approach. These may include the Grand Challenges in Engineering defined by the National Academy of Engineering [26]. In addition to being very interesting to students, these types of courses provide students with a context for learning which may improve their retention of basic concepts.

A second common factor in many first year programs is an emphasis on system level design and development of approaches to understanding and dealing with complex problems such as sustainable energy, environmental monitoring, assistive devices for the disabled, or control of transportation systems. These types of projects are expected to bring more perceived coherence to the curriculum that follows and to provide students with a sense of satisfaction and accomplishment. Assessments of improvement in retention and pedagogical impact will lead to future development and modifications of these approaches.

These recent trends in engineering education and curriculum reform may offer opportunities to include DSP content in the early curriculum in a more distributed manner rather than offering it as a single course. DSP modules may become basic building blocks like other basic core concepts

Theme based ECE curriculum redesign can provide students with a more integrated understanding of the discipline. For example, in a Duke University reform effort the theme for the introductory and core courses is Integrated Sensing and Information Processing [27, 28]. DSP components easily could be included in such a program at both the sensing and processing levels. Another approach to department level reform at the University of Utah [29] uses system-level design integrated into individual courses or across multiple courses. Since most system-level design involves some data acquisition and processing, there is potential to make DSP an important component. The concept of a spiral curriculum structure [30] in ECE also proposes a more integrated curriculum with less traditional compartmentalization.

### **4. ASSESSMENT OF STUDENT LEARNING**

This wide variety of possible first year courses and the possibilities of distributed teaching of DSP in multidisciplinary first year courses or vertically integrated curricula raise challenging questions of how and when to do assessments. Faculty seeking to improve student learning through course or curriculum modification need reliable metrics to assess the impact of the changes. The concept inventory approach to a specific area was pioneered in physics [31] and a specific concept inventory for DSP has been tested [32]. Typically these tests of concept understanding are administered at the beginning and end of a class to help determine the impact of a change in course content, structure, or delivery such as active learning. The application of concept inventories should be explored in the context of distributed topics learned in multiple multidisciplinary courses.

The National Academy of Engineering provides good guidelines for approaching assessment through the 2008 report entitled “Metrics for Assessing Engineering Instruction: What Gets Measured and What Gets Done”

[33]. Borrego [34] has recently explored “Conceptual Difficulties Experienced by Trained Engineers Learning Educational Research Methods.” Other perspectives may be found in Lord [35] and the recent NAE publication “Synthesis Research: Evaluating Instructional Scholarship in Engineering” [36]. The National Science Foundation continues to fund research in how to better assess teaching and learning.

## 5. FUTURE DIRECTIONS

New approaches to modernizing the ECE curriculum offer exciting possibilities to make the undergraduate program more engaging and relevant to students and possibly more streamlined and efficient. However these approaches also present challenges in terms of course design, concept coverage, resources, and assessment. DSP is becoming more fundamental, like calculus, so there are many ways to present it and distribute it. In addition, in the context of curricular reform efforts with a desired focus on multidisciplinary design, project based learning, vertically integrated themes, and complex system experience, narrowly focused introductory courses are becoming less prevalent in the first year.

Over the past ten years several institutions have introduced lower division DSP courses which made pioneering efforts both to restructure the EE curriculum and to motivate and encourage students. However, the future of DSP in the lower division make take many different forms. As application of DSP has spread to other disciplines, the need for entry level DSP education has grown. In addition, DSP can play an important role in a variety of complex system based course sequences.

A next step in innovative DSP education in the broad context of the EE curriculum or the engineering curriculum may focus on development of portable adaptable modules for flexible use in this wide variety of new structures. This will lead to challenges in establishing suitable sequencing so that students will have integrated design experiences and still follow some logical progression of concept development. Assessing module use will also require new thinking because the varied reform structures will lead to diverse paths through traditional curriculum content, and there will be wide variability in the order, the time frame, and the context in which DSP modules might be used. It is possible that DSP techniques of audio and video analysis may also play a role in automated assessment of learning through monitoring of individual student interactions and overall classroom environment.

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